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ORIGINAL PAPER

Nutrient dynamics associated with leaf litter decomposition of three agroforestry tree species (*Azadirachta indica*, *Dalbergia sissoo*, and *Melia azedarach*) of Bangladesh

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Abstract: *Azadirachta indica* A. Juss, *Dalbergia sissoo* Roxb., and *Melia azedarach* L. are little studied species in nutrient return capabilities from leaf litter decomposition to maintenance of the soil fertility despite their importance in agroforestry practices of Bangladesh. A leaf litter decomposition experiment was conducted using a litterbag technique to assess the nutrient return efficiency of these species. The decomposition rate of leaf litter was highest for *M. azedarach* and lowest for *D. sissoo*. Rainfall and temperature of study sites showed a significant ($p<0.05$) positive relationship with the rate of leaf litter decomposition. The highest decay constant was observed for *M. azedarach* (6.67). Nitrogen and Phosphorus concentration in leaf litter showed a decreased trend sharply at the end of the first month, whereas rapid decrease of Potassium concentration was reported within 10 days. Conversely, higher concentration of nutrient was observed at the later stages of decomposition. All three species showed a similar pattern of nutrient release (K > N > P) during the decomposition process of leaf litter. Among the studied species, *D. sissoo* was best in terms of N and P return and *A. indica* was best in terms of K return.

Keywords: agroforestry; decay constant; decomposition; leaf litter and nutrient dynamics

Introduction

Depletion of nutrients and soil's organic matter is a serious threat to agricultural production and food security in many tropical countries (Lal 2004; Ajayi 2007). Such a decline leads to a decrease in agricultural productivity due to nutrient depletion and poor environmental quality (Lal 2004). Litter usually improves soil quality through the addition of organic matter, which enhances the soil's water holding capacity, water filtration, biodiversity, activity of soil microorganisms, and nutrient concentrations (Guo and Sims 1999; Bossa et al. 2005; Ngoran 2006). More than half of the nutrients taken up by plants return to the soil through several ways, among which decomposition of litter contributes the majority (Cole 1986) and the nutrient release patterns are related to climatic condition and litter quality (Khietwtam and Ramakrishnan 1993). Litter usually contains lower nutrients, compared to living plants (Toky and Ramakrishnana 1983; Sundarapandian and Swamy 1999). Among litter types, leaf litter contains comparatively higher concentrations of nutrients and returns the major source of nutrients to the soil (Meentemeyer et al. 1982; Anderson and Swift 1983; Liu et al. 2000). Amount of nutrients delivered by annual litterfall to the soil through decomposition is an important factor for sustainable forest production and provides an index of forest productivity (Swift et al. 1979; Attiwill and Leeper 1987; Guo and Sims 1999; Villela and Proctor 1999; Wardle 2002).

Agroforestry, a sustainable land-use system (Chundawat and Gautam 1993), and optimal production of any agroforestry practice is influenced by the combination of tree and agricultural crops, amount of soil nutrients, moisture conditions, and rate of organic matter decomposition (Nair 1984). It is believed that agroforestry promotes a more efficient cycling of nutrients than

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traditional agriculture system (Smiley and Kroschel 2010). *Azadirachta indica* A. Juss., *Dalbergia sissoo*Roxb., and *Melia azedarach* L. have been extensively planted in different agroforestry practices in Bangladesh (Baksha and Basak 2000) with combination of different crops (e.g. paddy, wheat, pineapple and vegetables) (Lodhiyal and Lodhiyal 2003). The selection of these tree species is usually guided by their morphological characteristics and local demand (Baksha and Basak 2000); however, the prime challenge of better management and sustainable production within agroforestry practices depends on the selection of tree species having efficient nutrient return capabilities (Khietwtam and Ramakrishnan 1993; Ibrahima et al. 2008) through the decomposition of litter which influences the nutrient cycling and formation of soil organic matter. Therefore, the aims of the present study were to examine and compare the decomposition and nutrient releasing pattern during the leaf litter degradation of *A. indica*, *D. sissoo*, and *M. azedarach*.

Materials and methods

Description of study site

This study was conducted in Khulna University campus in 2008 under mixed plantations of *A. indica*, *D. sissoo*, *Lagerstroemia speciosa*, *Emblica officinalis*, *Swietenia mahagoni*, *Leucaena leucocephala*, *Cassia siamea*, *M. azedarach* and so on. The tree density of the site is 800 stems·ha^{-1}. The climate is humid-subtropical with a mean temperature of 18–23ºC in winter and 27–31ºC in summer. Mean annual rainfall is 1980 mm; summer (May to September) contributes about 81% of the annual rainfall while winter season contributes about 19% of rainfall. Soil is clayey and pH is around 7.9.

Sample collecting and processing

The leaf litter decomposition experiment was conducted using a litterbag technique (Mason 1977) for five months. Bulks of yellowish senescent leaves of *M. azedarach*, *A. indica* and *D. sissoo* were collected during the peak period of leaf shedding (March 2008). Leaf litter was air-dried at room temperature and mixed thoroughly. Two grams of leaf litter for individual species were taken as an individual sample. Individual samples were placed into a nylon bag of 300 mm×150 mm with 1-mm^2 mesh size. To prevent the leaves from folding and clumping they were laid flatly inside the bags. Eighty bags for each species were placed in the field and 10 bags were brought back to the laboratory for calculating fresh to oven-dry weight ratio at 80ºC to constant weight.

Ten bags for each species were collected at ten days intervals for the initial month and subsequently at monthly intervals for the remaining months. The collected samples were then gently washed to remove sediments and dirt particles by using a soft brush under slowly running tap water followed by final rinsing in distilled water. Each sample was then oven-dried at 80 ºC to constant weight.

Mass loss and decay constant

The loss in dry mass of samples was calculated from initial converted oven-dry weight and remaining mass. The rate of decomposition was calculated from percentage of mass loss divided by respective days of collection. Decay constants for leaf litter were calculated using negative exponential decay model.

$$X / X_0 = \exp^{(-kt)} \text{ (Olson 1963)} \tag{1}$$

where, X is the weight remaining at time t, X_0 the initial weight, exp the base of natural logarithm, k the decay rate coefficient and t is the time in year.

Sample digestion and nutrients measurements in leaf litter

The oven-dried samples were processed according to Allen (1974). The processed leaf samples were weighted to 0.2 g and put into a digestion flask. Micro-kjeldahl digestion was carried out for the samples and the extract was filtered and diluted to 100 mL with distilled water (Allen 1974). Nitrogen (N) and Phosphorus (P) concentrations in sample extracts were measured according to Weatherburm (1967) and Parsons et al. (1984), respectively using UV-Visible Recording Spectrophotometer (SHIMADZU, UV-160A, Japan). Potassium concentration in sample extracts was measured by Atomic Absorption Spectrophotometer (PERKIN ELMER 4100, USA). The nutrient amounts released from leaf litters were calculated as differences between initial and final absolute amounts and also expressed as percentage of initial amounts.

Statistical analysis

The rates of mass loss and nutrients (N, P and K) concentrations in leaf litter were compared among the different stages of decomposition of the study and also with the tree species. This comparison was performed by two-way analysis of variance followed by Duncan Multiple Range Test (DMRT) using SAS 6.12 statistical software. Moreover, the relationships among the rate of leaf litter decomposition, monthly rainfall amount and monthly mean temperature were evaluated by correlation analysis using SAS 6.12 statistical software.

Results

Decomposition pattern

The mass was to the tune of 46%–63% in the three species at the end of the experiments (Fig. 1). Comparatively (ANOVA, $p<0.05$), a rate of decomposition of *M. azedarach* leaf litter was higher, whereas leaf litter of *D. sissoo* showed a lower rate of decomposition (Fig. 2). Decay constants (k) were calculated for the whole experiment. The decay constant (k) was comparatively higher (6.67) for *M. azedarach*, followed by *A. indica* (5.12) and

D. sissoo (3.91). The rate of leaf litter decomposition of each species showed a significant (p<0.05) positive relationship with monthly rainfall (range of r value is from 0.86 to 0.88.) and temperature (range of r value is from 0.71 to 0.81).

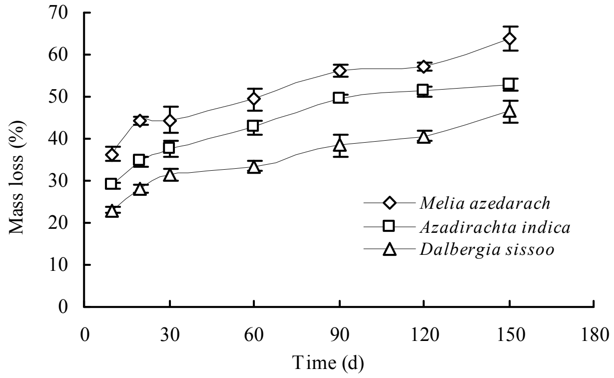

Fig. 1 Mass loss (%) of leaf litter of *Melia azedarach, Azadirachta indica* and *Dalbergia sissoo* during the decomposition process.

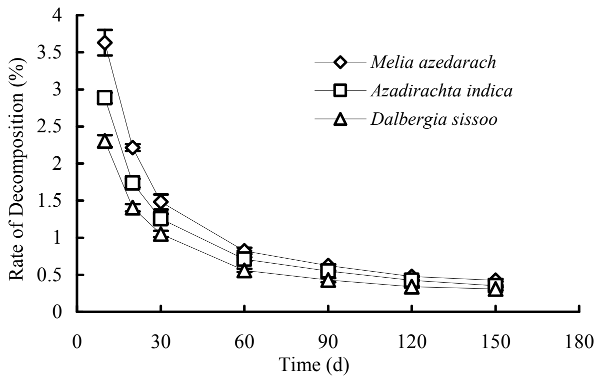

Fig. 2 Rate of decomposition (%) of leaf litter of *Melia azedarach, Azadirachta indica* and *Dalbergia sissoo* during the decomposition process.

Nutrients in leaf litter

The initial concentration of N and P in the leaf litter of *M. azedarach* was comparatively (ANOVA, p<0.05) higher whereas a higher K concentration was observed in *A. indica* (Table 1). Rapid decrease in N and P concentration was observed at the end of first month, while rapid decrease in K concentration was reported within 10 days of the decomposition experiment. Conversely, after the rapid decrease, nutrient (N, P and K) concentration was increased at the later stages of decomposition of leaf litter. Moreover, leaf litter of all the species showed a similar pattern (K>N>P) in decreasing nutrient concentration throughout the decomposition process (Fig. 3−5). Comparatively higher amounts of N (about 0.03 $kg \cdot t^{-1}$) and P (2.8 $kg \cdot t^{-1}$) were added to the soil from the leaf litter of *M. azedarach* whereas higher amount of K was added to the soil from *D. sissoo* leaf litter (Table 2).

Table 1. Initial concentration of nutrients in leaf litter of different species

Species	Nitrogen ($\mu g \cdot g^{-1}$)	Phosphorus ($\mu g \cdot g^{-1}$)	Potassium ($\mu g \cdot g^{-1}$)
Melia azedarach	35	3542	7268
Azadirachta indica	30	813	7455
Dalbergia sissoo	32	720	5464

Table 2. Amount of nutrients added from the leaf litter of different species

Species	Nitrogen ($kg \cdot t^{-1}$)	Phosphorus ($kg \cdot t^{-1}$)	Potassium ($kg \cdot t^{-1}$)
Melia azedarac	0.03	2.80	5.20
Azadirachta indica	0.02	0.59	6.04
Dalbergia sissoo	0.03	0.54	4.01

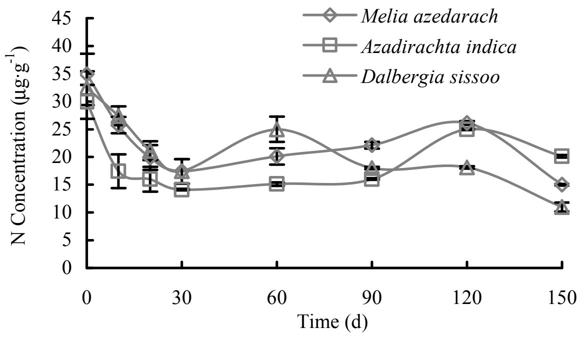

Fig. 3 Nitrogen concentration ($\mu g \cdot g^{-1}$) in leaf litter of *Melia azedarach, Azadirachta indica* and *Dalbergia sissoo* at different stages of decomposition

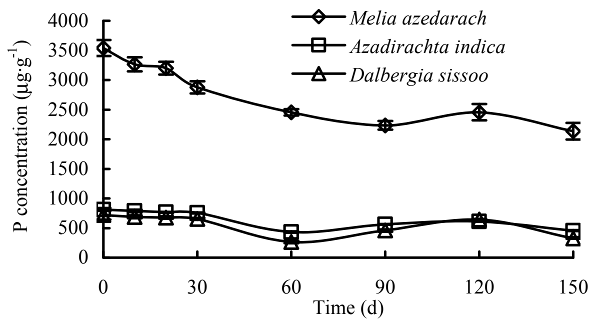

Fig. 4 Phosphorus concentration ($\mu g \cdot g^{-1}$) in leaf litter of *Melia azedarach, Azadirachta indica* and *Dalbergia sissoo* at different stages of decomposition

Discussion

Decomposition pattern

Comparatively a rate of decomposition of leaf litter was higher during the first 30 days, followed by a gradual mass loss for the subsequent 120 days (Fig. 2). This pattern of leaf litter decompo-

sition indicates two stages (Berg 1986; Takeda 1995; Semwal et al. 2003). The initial stage is typically met by a relatively larger decrease in mass which is usually attributed to leaching of readily soluble substances and non-lignified carbohydrates (Parsons et al. 1990; Ibrahima et al. 1995; Prescott 2005; Ibrahima et al. 2008). The further decrease in mass loss may be attributed to the release of a higher percentage of recalcitrant fractions like cellulose, lignin and tannin at the advanced stage of leaf litter decomposition (Bloomfield et al. 1993).

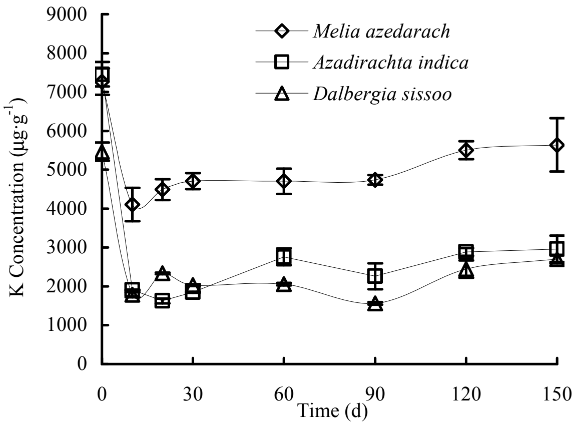

Fig. 5 Potassium concentration ($\mu g \cdot g^{-1}$) in leaf litter of *Melia azedarach, Azadirachta indica* and *Dalbergia sissoo* at different stages of decomposition

The studied species showed comparatively faster mass loss than other multipurpose tree species of the central Himalaya, India as reported by Semwal et al. (2003) and this variation in mass loss may be due to the litter quality and site factors (Heal et al. 1997). The decay constant varied from species to species and from temperate to tropical regions (Brinson 1990; Takeda 1996; Lockaby and Walbridge 1998; Torreta and Takeda 1999). Again, microclimatic variation in decay constant was also reported to be a factor within a given climatic region (Anderson and Swift 1983; Verhoef and Gunadi 2001). The decay constant range of this study (k= 6.67−3.91) was found to be similar with the range of leaf litter decay of tropical trees as reported by Budelman (1988) and Palm and Sanchez (1990). The higher decay rate of leaf litter decomposition for *M. azedarach* could be an indicator of higher litter quality, compared to other studied species.

Nutrients in leaf litter

Comparatively higher initial concentration of N and P in leaf litter of *M. azedarach* and higher K concentration in leaf litter of *A. indica* indicated that capabilities of these species to retranslocate these nutrients were lower during the senescence of leaves (Berg and Laskowski 2006; Hagen-Thorn et al. 2006). Nutrients release from leaf litter follows a sequential lowering concentration in K>N>P, which is similar to the mobility pattern of these nutrients (Eaton et al. 1973; Waring and Schlesinger 1985). The faster decreasing of K concentration from leaf litter was observed as it is a non-structural element (Tisdale et al. 1993) and also liable to be the most leachable cation during the decomposition of litter (Berg and Staaf 1987; Herra´ez and Ferna´ndez Marcos 2000; Guo and Sims 2002). A pattern of two distinct phases of decreasing nutrient concentration (N, P and K) was observed during the decomposition process (Fig. 3−5). At the first phase, an initial rapid decrease in nutrient (N, P and K) concentration was observed and the subsequent phase was immobilization of nutrients (Herra´ez and Ferna´ndez Marcos 2000; Guo and Sims 2002; Moore et al. 2006; Alvarez et al. 2008; Hough and Cole 2009). The initial rapid decrease of nutrients concentration may be ascribed to the loss of the soluble forms of nutrients at the initial stages of decomposition (Mahmood et al. 2007) and a slower release of nutrients at the later stages of litter decomposition governed by refractory components (Schlesinger 1985; Herra´ez and Ferna´ndez Marcos 2000). On the contrary, increased concentration of nutrients (N, P and K) at different stages of decomposition (Fig. 3−5) was attributed to microbial or non-microbial immobilization in the residual leaf litter, atmospheric deposition or the activity of fungi or heterotrophic organisms (Berg and Staaf 1987; Cameron and Spencer 1989).

Conclusion

The amount of nutrients added to the soil through leaf litter depends on the litter quality, climate, individual nutrient concentration and their dynamics during the process of decomposition. The added nutrients may contribute to the sustainability of soil fertility, which is becoming an important phenomenon for agroforestry practices. Among the considered species, *D. sissoo* was found to be the best in terms of N and P while *A. indica* was best in terms of K.

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